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ORIGINAL ICE STRUCTURES PRESERVED IN UNCONSOLIDATED SANDS

CHARLES P. BERKEY AND JESSE E. HYDE

The purpose of this paper is to describe and illustrate certain structures occurring in unconsolidated sands of glacial origin. These structures are so inconsistent with the usual behavior of sands during accumulation that it is believed they point to special conditions that could have prevailed only during the glacial epoch. It may be that they give a clue to marginal structures within the moving ice sheet itself.

The deposit is located in New York City between 134th and 135th streets, west of Broadway. It may be seen from the Riverside viaduct which crosses the Manhattanville depression. It appears as an irregular sand and gravel hill, probably only the remnant of a once much more extensive deposit. While it has been opened at several points to obtain building sand and abnormal features are to be seen in several of them, recent excavation for a building at the corner of 135th Street and Broadway has revealed the most interesting exposures.

With the exception to be noted, assortment of material is excellent. Sands of a wide range in size are extensively represented, usually well assorted and plainly stratified. Rarely the finer silts and clays occur in interstratified streaks. On the other hand, some of the beds are made up of pebbles whose diameters are measured in inches. On the whole the materials are coarse, i.e., sands and gravels rather than silts and clays. The individual layers are usually thin, a few inches only, but some of the finer-grained beds may reach a foot or two in thickness.

The exception to this rather thorough assortment of materials is found in masses of bowlder clay which are intimately associated with the other types. The bowlder-clay structure is very coarse. Bowlders two or three feet through are not unusual and one over six feet in diameter is closely associated with sand and gravel.

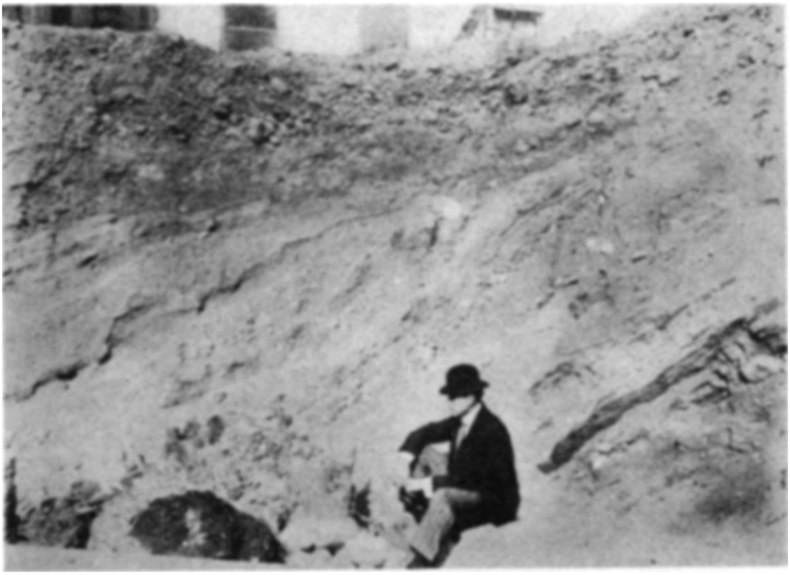

FIG. 1.—Assorted sands and gravels standing as steep as 68 degrees at some points. Left is northerly.

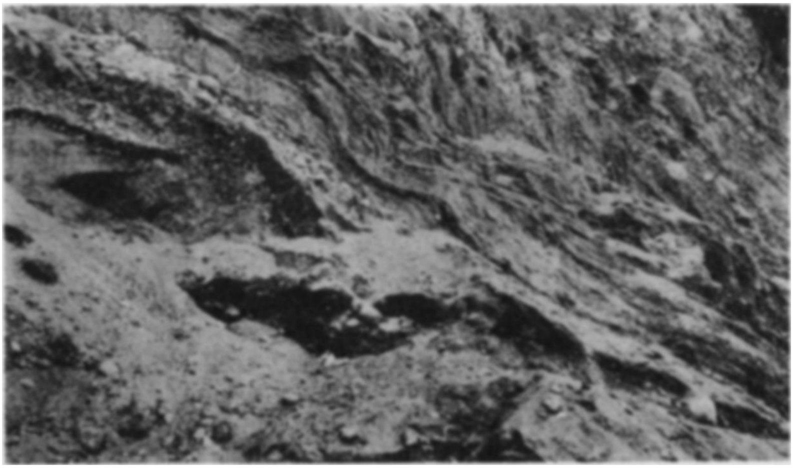

FIG. 2.—Contorted sands associated closely with coarse and unassorted gravels. Right is northerly.

The occurrence of these strikingly unlike deposits so closely interrelated is a prominent feature. Conditions suitable for the handling of large bowlders and the accumulation of till cannot well be regarded as consistent with thorough assorting and deposition of finely stratified sands at the same time and place.

The beds almost never lie flat; when they do it is only for a few inches. They are almost invariably inclined toward the north, northwest, or northeast; that is, against the general ice movement as indicated by striae of the vicinity. Although the maximum angle of repose for unconsolidated sands under subaerial conditions is about 34°, the dips here commonly range from 10° through 20°, 30°, 40°, to 60°. Inclinations of 68° and 71° have been observed and at one point, for a vertical height of four or five feet, the beds are perpendicular or even slightly overturned.[1]

Occasionally contortion is observed but only to a very limited extent. Faulting of several inches displacement has been seen in such form that it could not possibly have happened by slipping on the growing margin of a delta deposit. In one instance the beds on either side of the fault dip away from the fault plane, on the one side at an angle of 67°, on the other side at an angle of 40°. In another instance a small thrust fault of an inch displacement was observed. It is of significance that the thrust was from the north (Fig. 3).

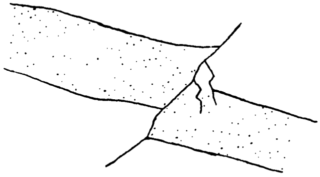

FIG. 3.—Small overthrust in unconsolidated sands, thrust from a general northerly or northwesterly direction.

In order to explain these occurrences and the ones to follow, it may be assumed that the deposit was laid down near the margin of the ice sheet. The material is so well assorted and the bedding is so sharp that it is necessary also to conclude that the deposit was originally water laid. Possibly the dips were originally toward the ice sheet as they are now found, but the angles of inclination could not have been as great as they are now.

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[1] Similar structural features are noted by Professor T. C. Chamberlin in gravel hills in Tippecanoe Co., Indiana. ("Hillocks of Angular Gravel and Disturbed Stratification," *A.J.S.*, XXVII [1884], 378–90.)

It seems necessary to assume that, following the deposition, and while the whole mass was thoroughly saturated with water, it was frozen and incorporated in the ice and that there was then movement of the ice sheet with its included material. The movement in the latter, while probably not great, was sufficient to cause the oversteepening of the sands as they are now found, and the slight amount of contortion and faulting which occurs. Under

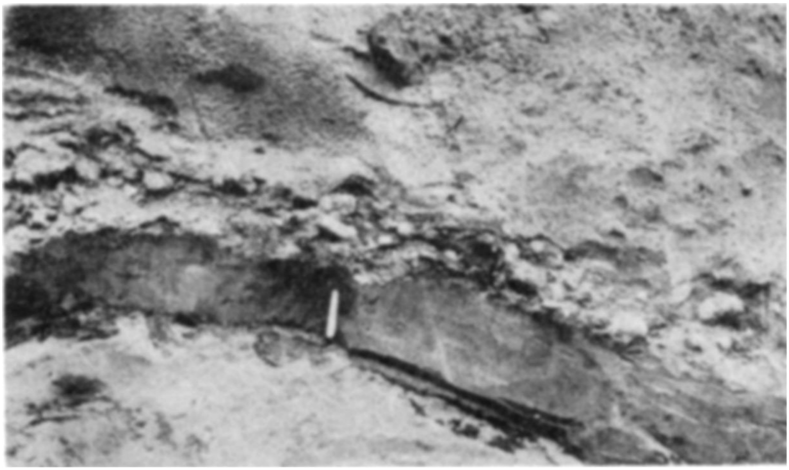

FIG. 4.—A fine sand layer which seems to have been arched since deposition and in the process developed V-shaped notches along the stretched upper margin which are now filled with coarser sand. See explanatory sketch, Fig. 5.

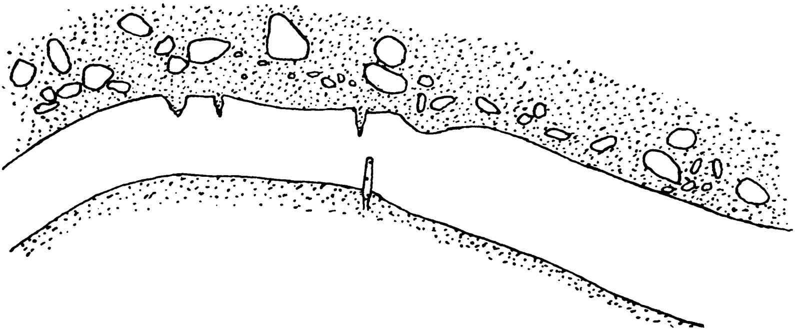

FIG. 5.—Explanatory drawing to accompany the photograph, Fig. 4

these conditions probably the interstitial ice became an efficient binder between the individual sand grains and caused the whole to behave as a rock mass, yielding slowly to gradual stresses and breaking or shattering or faulting like a true rock when subjected to sudden changes.

Subsequent melting of the ice left everything in place, and the whole complex mass suffered so little distortion from shrinkage with the loss of its ice matrix that these secondary structural features are still preserved.

With this statement of the thesis some of the minor structures may be described. All of them occur in the finer sand deposits exposed in the excavation at 135th Street and Broadway.

On the south wall there is a low regular arch several feet across in a bed of soft fine clayey sand, perhaps eight inches thick. It is overlain and underlain by much coarser sands. In the upper part there are three narrow vertical cracks some three or four inches deep where the fine sand has been pulled apart, as if by stretching, and the coarse material from above has filled the openings. In this case, the difference in the constitution of the two beds seems to have been a controlling factor and the two types of material behaved somewhat differently, the fine-grained sand layers moving as a unit, and cracking on the upper stretched surface of the arch. The fine sand is now so soft as to be easily pared with a knife and the coarse material runs out from above and below it by its own weight.

At one point on the north wall of the excavation, and less perfectly at several other places, the sand preserves what seems to be the original shattering and cracking of the frozen mass. It is in very fine-grained sand, easily trimmed down without dulling a knife blade. The fracture lines are decidedly darker than the mass of the sand, sufficiently so to bring out the structures in the accompanying photograph. The original sedimentary structure of the sand is preserved and shows distinctly to what extent the whole was crushed and faulted. It is in fact a sand deposit breccia of extremely complicated structure.

A few feet distant from the last, a wholly different structure is preserved. This is in quite fine-grained, clayey sands which

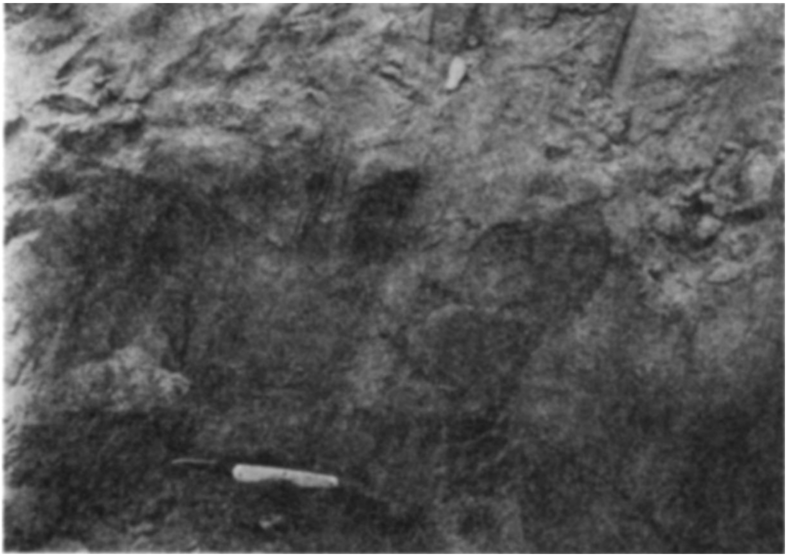

FIG. 6.—Brecciation and minor faulting in unconsolidated stratified sands. For explanatory sketch of the detail see the accompanying drawing, Fig. 7. Left is northwesterly.

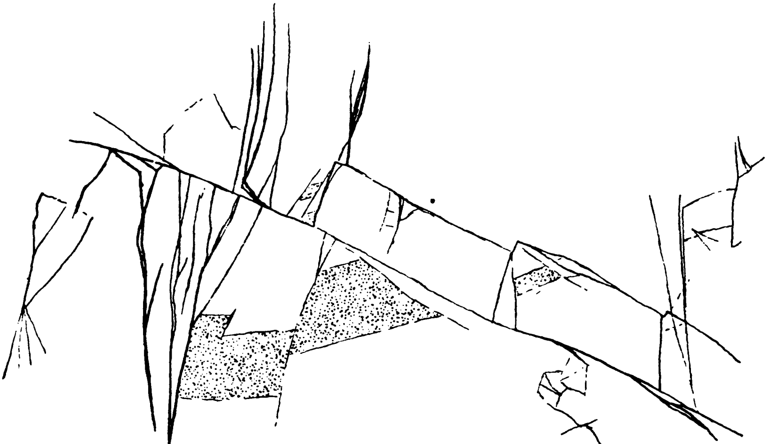

FIG. 7.—Explanatory drawing illustrating the most prominent detail of the photograph, Fig. 6, and compiled in part from other photographs of the same occurrence. Only a few of the angular "fragments" of sand are indicated to show the brecciation.

alternate with several thin streaks of coarse sand, the latter seldom exceeding an inch or two in thickness. These beds are inclined at considerably more than the angle of repose under water, reaching about 40°, and have undoubtedly been oversteepened, although scarcely distorted. Traversing this series is a thin, nearly horizontal bed of rather coarse sand, six feet long and one to three inches thick. This sand is for the most part horizontally bedded, but cross-bedding also occurs, showing that it is undoubtedly water laid in its present position. The remarkable thing is that the cross-streaks of the inclined series are continuous above and below this horizontal streak or layer and are interrupted by it, showing that the horizontal bed came in subsequent to deposition and oversteepening.

It is unquestionable that the beds above and below the horizontal one were once continuous. Assuming them laid down, frozen, and over-steepened as described above, it is postulated that a horizontal crevice was formed in the frozen mass and melting took place along it in the ice and that water currents of sufficient force to carry and rearrange the sands were allowed to enter. With the final thawing of the mass these delicate structures were not destroyed and are still preserved in the unconsolidated sands.

Other occurrences in the same deposit exhibit irregular mixtures of fine and coarse sands in which the finer-grained areas seem to represent a bed that has been broken into distinct blocks or has been drawn out into odd irregular stringers. This gives certain areas, several feet across, the appearance of a coarse breccia in which the finer sand areas constitute the angular masses, while the coarser sands fill up the interstitial spaces like a matrix. Again there are places where the oversteepened layers are so closely associated with others whose attitude is consistent with present conditions that the whole group almost baffles explanation in detail.

In conclusion it may be worth noting that most of the structures described and illustrated could not have been produced in these sands in their present unconsolidated condition. The steeper layers on the other hand could not have been originally deposited in their present attitude. It is necessary to introduce some intermediate history. There is little doubt but that the oversteepening, the brecciation, faulting, and some of the mixing of materials of different types were caused by glacial advance involving the whole mass in some way in differential movements. But before that could be accomplished much of the material had to be assorted, and this had been done, as the great variety and excellent sizing

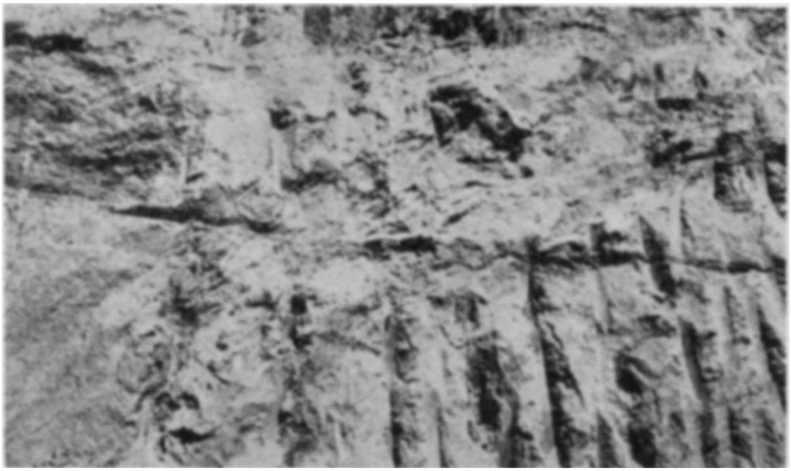

FIG. 8.—Photograph of the thin horizontal sand layer cutting inclined assorted sands. Note the cross-bedding in the horizontal layer at the right. See explanatory drawing, Fig. 9 below. Left is northwesterly.

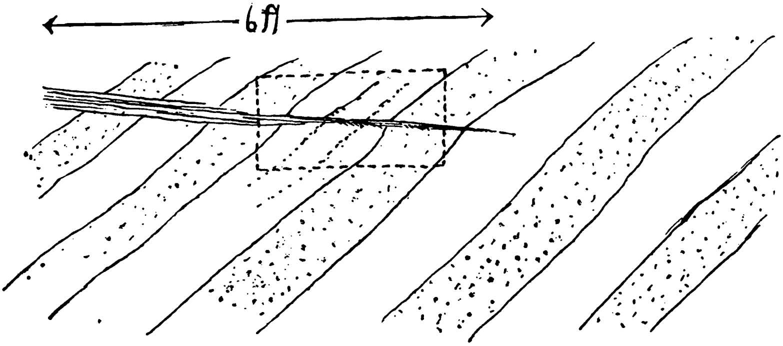

FIG. 9.—Diagrammatic drawing to accompany photograph of inserted sand layer, Fig. 8. The dotted area indicates the portion shown in Fig. 8.

of grains indicate, under extremely variable conditions and in complex relations to unassorted masses. This seems to point to marginal and superglacial accumulation in such relation to the general ice mass that the particles subsequently became incorporated with it and partook of its later movements. These later movements developed the structures just described which may not have been uncommon in other drift deposits but which are probably seldom so well preserved.

Although the original ice behavior is indicated by these structures it is doubtful whether the observations are of much value toward a better understanding of ice flowage. The ice must have been unusually heavily saturated with these earthy matters, the sands and gravels, and it is probable that differential movements were largely encouraged by their differences of texture.